FATIGUE LIFE DESIGN OF WIND TURBINE COMPONENTS FOR TOTAL LIFE

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THEME

Fatigue Analysis, Wind Turbines, Planetary Gears

SUMMARY

To prove that the planet carrier of a wind turbine has a fatigue life of 20 years, measured load histories were used, each representing a time section of 10 minutes. The measured load sizes are the generator moment and the deformation of the machine foundation. Furthermore, the pre-stressing of the bolts including the contact and non-linearity and the bending moment resulting from the weight of the machinery itself were taken into account.

The fatigue life calculation is carried out using the stress results of the static Finite Element Analysis standard load cases which have been gauged by scaling with the measured loads using the results of the standard load cases. Stress S-N curves according to the guidelines set by Germanischer Lloyd were generated and used.

With the help of a mesh which was only rough to start with, and a non-local modified S-N curve, a search was carried out for the critical areas of the structure. In a second step these areas were divided into finer sections and the S-N curves were modified locally with the aid of the related stress gradients. This second, more complex calculation resulted in a changed fatigue life prognosis in a less conservative direction.

This indicates the recommended procedure. For the addition and extrapolation of 10 minute measured sections for a fatigue life of several years, the influence of the sequential order was analysed. It could be seen that for the relatively short periods of time the mean loads were often almost constant. This is due to the measuring procedure which was used to record specific scenarios. The transition from one measured scenario to another is often linked to a change in the mean load which is not included in the measured loads themselves. It does not occur until the various load sequences are arranged, one behind the other. The influence of these transitions was analysed and a procedure suggested so that these effects can be taken into account.

KEYWORDS

Fatigue Life, Wind Turbine, Planetary Gear, Residuum, winLIFE

1: Introduction

For the design of wind turbines a large number of loading histories coming from measurements are used to cover the total range of operation. Based on these fatigue simulation results a prediction for the total life is done. This paper shows how to do this using MBS and FEA software together with winLIFE.

2. Simulation approaches

2.1. “Total World” Model inclusive Environment / MBS

In the case of large deformations, nonlinear effects and dynamic forces static the superimposing method reaches its limit and it is more suitable to use a **M**ulti-**B**ody-**S**ystem analysis in combination with FEA. In the MBS-model the total dynamic and nonlinear behaviour is solved. Compared to the static superimposing and scaling of unit load cases, there is no need to define separated unit load cases and split the load to take contact, rotation or nonlinear effects into account. But this method is much more time consuming. The procedure is shown in the following figure.

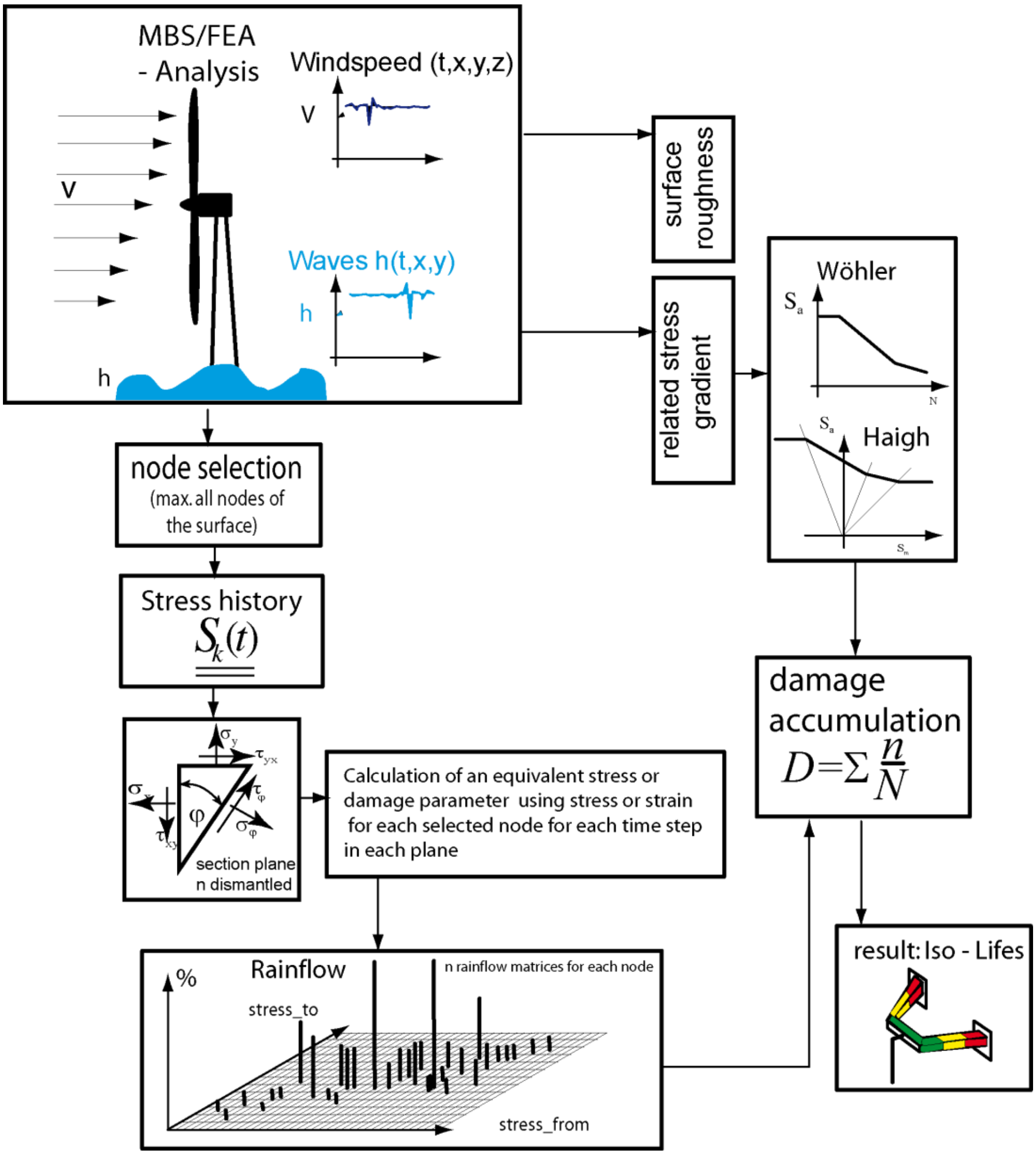


Figure 1: **"Total world" model of a total wind turbine by using MBS/FEA**

2.2 Superimposing and scaling static unit load cases from FEA

A very important procedure because of the calculation speed is to calculate the stress history of a structure by superimposing and scaling results from static unit load cases and (measured) load histories. This procedure is limited to only small deformations and the natural frequencies must be at least a factor 3 higher than the excitation frequencies of the loadings. The following diagram shows the principal way:

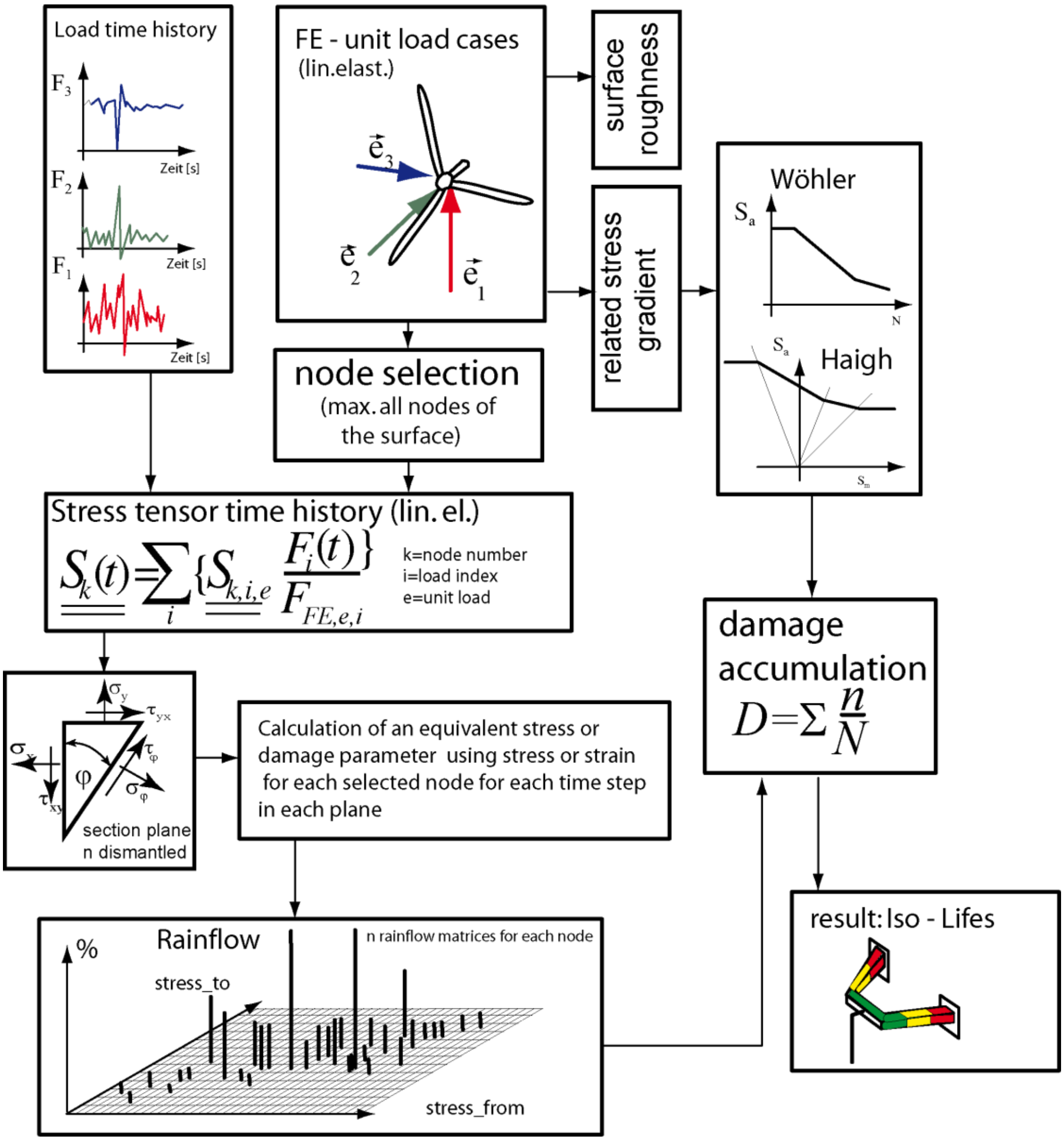


Figure 2: "Partial model " Superimposing and scaling static unit load cases

Note that elastic stresses are used. In the case of Elastic Stress Method to get realistic results these have to be transformed by modifying the S-N curve by the related stress gradient. If the Local Strain Approach is used a stress transformation is done with Neuber's rule. Another problem is that in the case of contact or rotating parts, the unit load case and the corresponding loads must be divided into more than one to take the contact or rotating into account. A detailed description of how to do this is described for wind turbines [7].

3.2 Data Transfer between winLIFE and MBS/FEA

Typically a data transfer between the FEA-Software and the fatigue software is done so that the fatigue analysis can be declared as a post-processor for FEA.

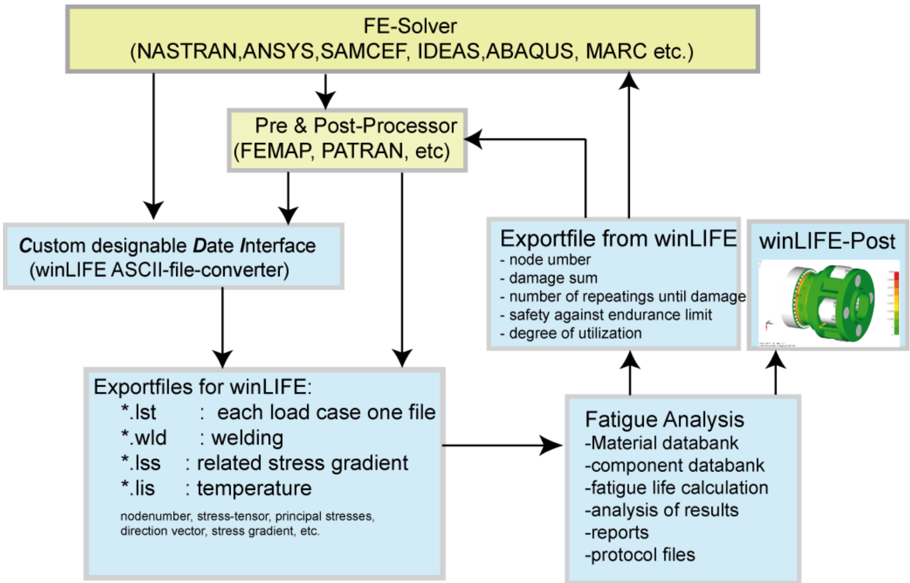


Figure 3: Data flow between FEA/MBS and fatigue software winLIFE

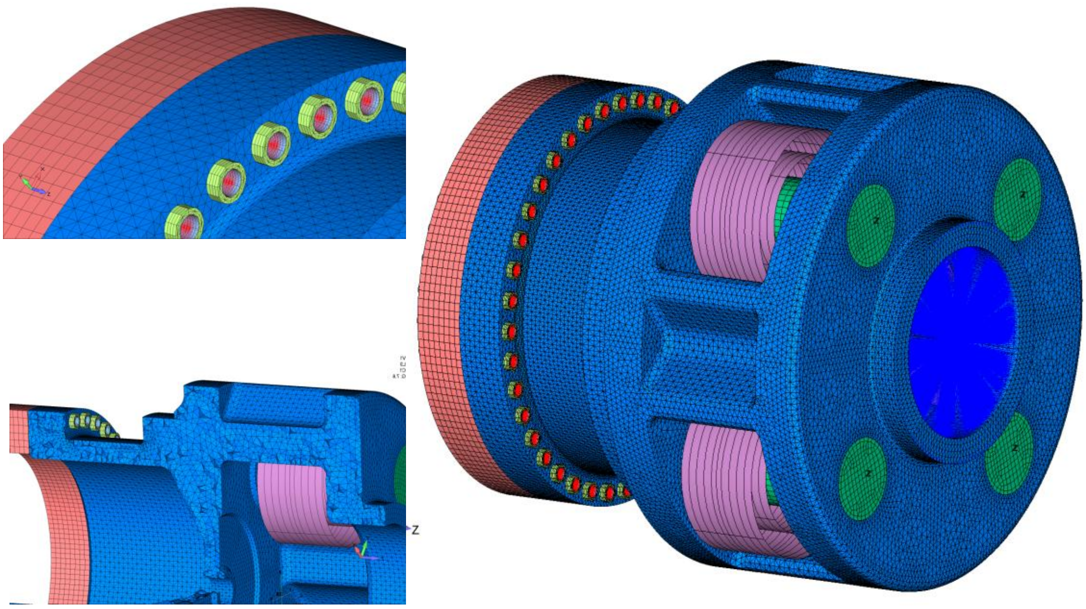


Figure 4: FEA-model of the gear (FEMAP)

4. Example Planetary support

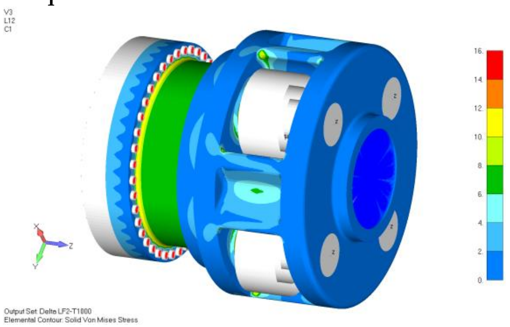
A model of planetary gear of a wind turbine is shown in figure 4.

It is loaded by the following 4 values

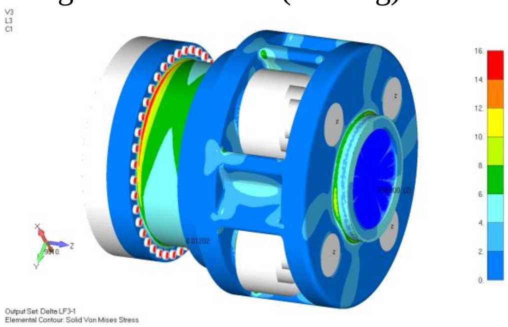
- Torque from the blades to drive the generator
- Weight of the rotating planetary support including the gears
- Pre-stresses of the bolts
- Forces resulting from the deformation of the machine support

The loading of these values is given as a result of measurements with a sample rate of 1000 Hz.

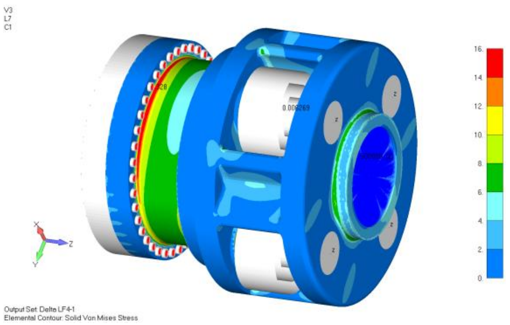
torque 1000 kNm



Weight load 743 kN (rotating)



Machine support 1000 kN (rotating)



Prestresses each bolt 650 kN

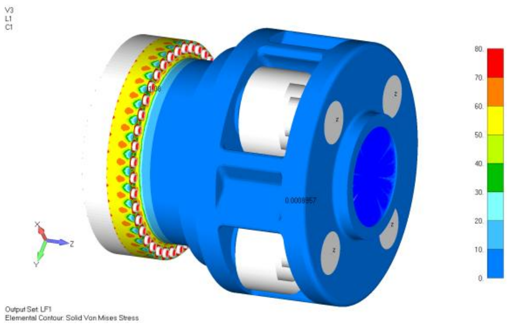


Figure 5: v. Mises stress results for the unit load cases Torque, Weight, Machine support, Pre-stressed bolts

Because the normal frequencies of the system are more than factor 3 higher than the exiting frequencies it is possible to solve the problem by superposition and scaling by the measured loadings.

The constant weight of the non-rotating parts leads to alternating stresses inside the rotating planetary gear. To take this into account the following procedure is necessary:

Two unit load cases, representing the gravity in x and y direction, were calculated by a finite element analysis. The load history for the X-direction is then defined by a sine function, the Y-direction by a cosine function. The combination of these two functions leads to a rotating gravity stress field.

All FEA calculations were done including the pre-stresses of the bolts.

The unit-load-cases for damage accumulation are done by reducing the load-case bolt-pre-stress from the other unit load cases.

5. Loading

The fatigue calculation is done for each measured 10 minutes sample and the result is extrapolated to a 20 year total life by multiplying the results according to the number of appearances in the life. But also it has to be considered in which order the loadings are acting. This shall be shown in the following figure. There is a loading coming from low wind speed scenario (left part) followed by a high speed wind scenario (middle) and finally again a low wind scenario (right).

If a fatigue calculation is done for only one scenario then the transitions between the different scenarios are not considered. However these transitions may have a higher damage effect than the scenario itself. The consequences to the stress strain path and the damage are shown in [7].

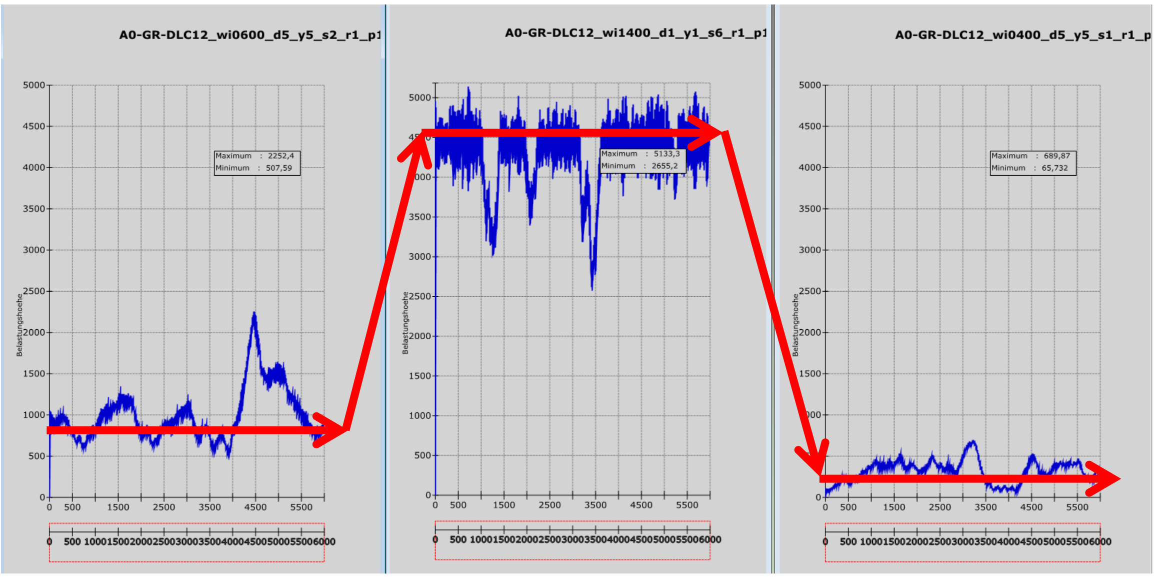


Figure 6: **Measured loading acting one after the other**

A solution can be to define an additional extra load which only contains the transitions between the single scenarios. An example for such a loading sequence is shown in the next figure which only contains such transition forces.

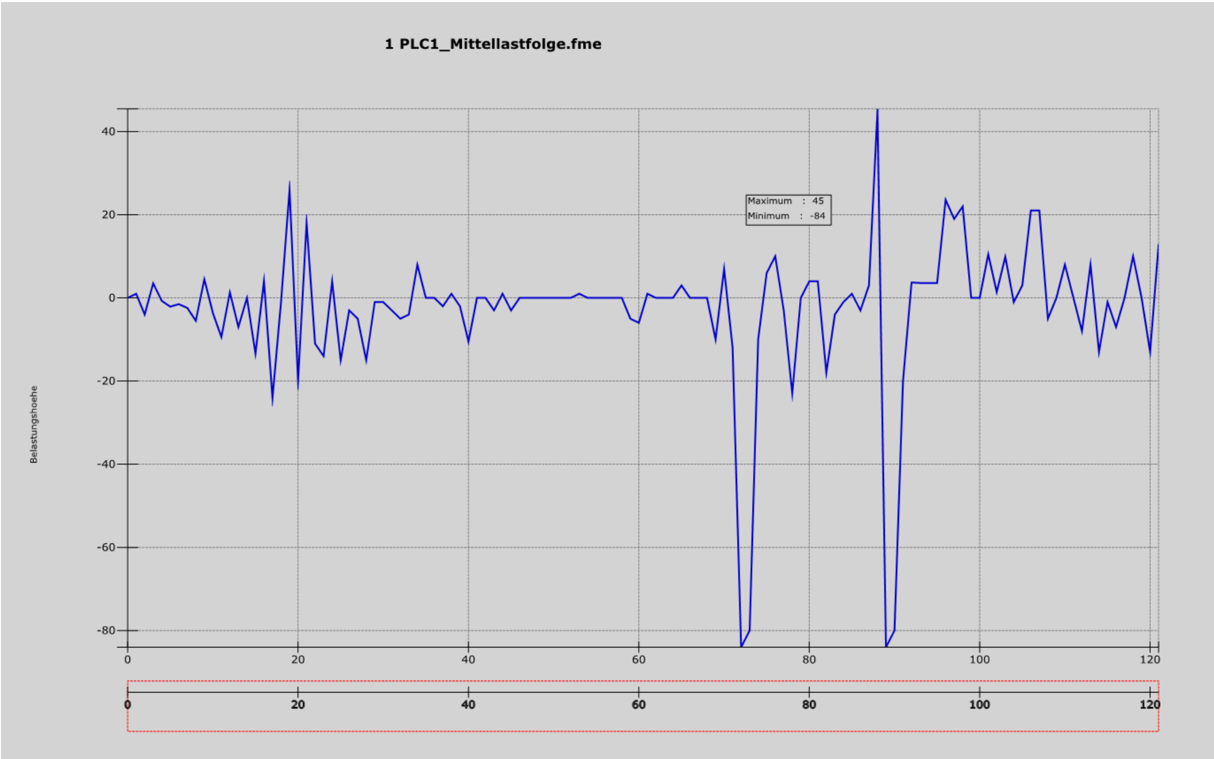


Figure 7: **Transition forces between the single scenarios to describe the influences of the sequence**

The sequence of the order of the scenarios can be analysed by this extra load by varying the sequence. It may be helpful to define a worst case, a best case and a probable case sequence to get an idea of the influence.

6. Fatigue calculation and results

6.1 Finding hot-spots using a course model

The FEA analysis - using the PLM-software FEMAP with NX Nastran - followed by the fatigue calculation using winLIFE was done by superimposing the results of unit load cases and scaling with measured loads. This was done according to the rules from GL [4].

The data of the analysed system are shown in the following table.

Number of nodes	1 280 015
Nodes on the surface	187 252
Damage on hot-spot 1	1.67E-10
Damage on hot-spot 2	9.3E-10

More than a hundred loadings representing the total life of a wind turbine were calculated and the resulting damage is shown on the surface of the model in figure 8 to get an overview.

To understand the contribution of each scenario single scenarios can be analysed separately. Figure 9 shows the equivalent amplitude; figure 10 shows the utilisation ratio. These results shown on the surface give a first idea of the hot spots in the structure.

To make an analysis in detail for each hot spot the rainflow-matrix (figure 11, the results in the Haigh-diagram (figure 12, and the S N-curve together with the amplitudes and the percentage damage of the amplitudes (figure 13) are used.

Results of fatigue life depend strongly on the mesh quality. To demonstrate this, a finer mesh was used in the range of hot spots.

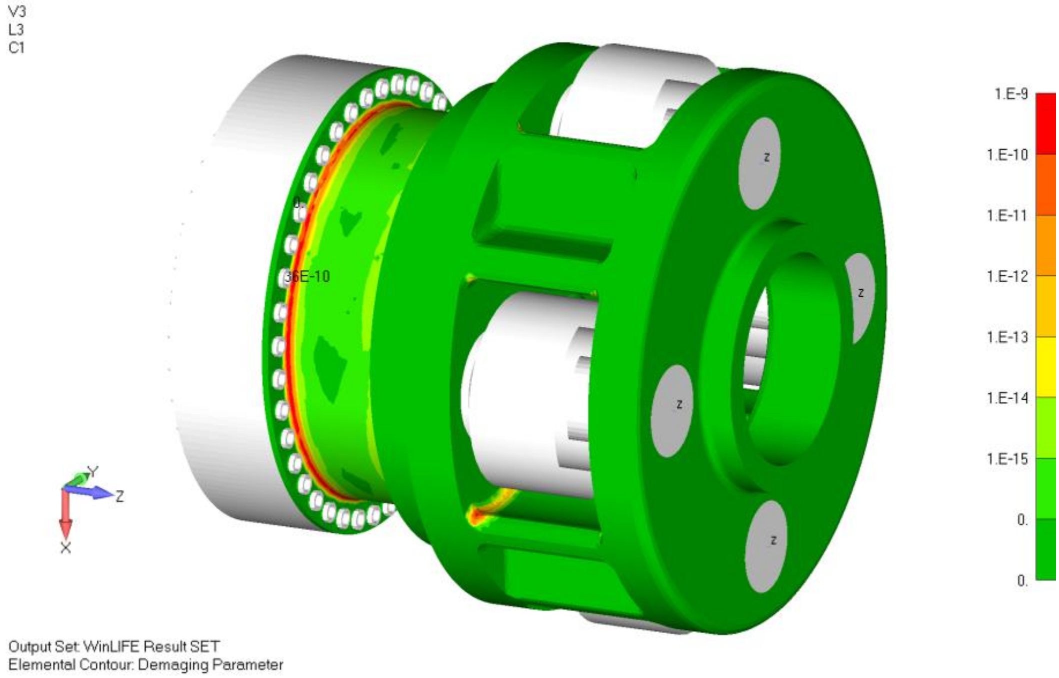


Figure 8: **total damage over all scenarios**

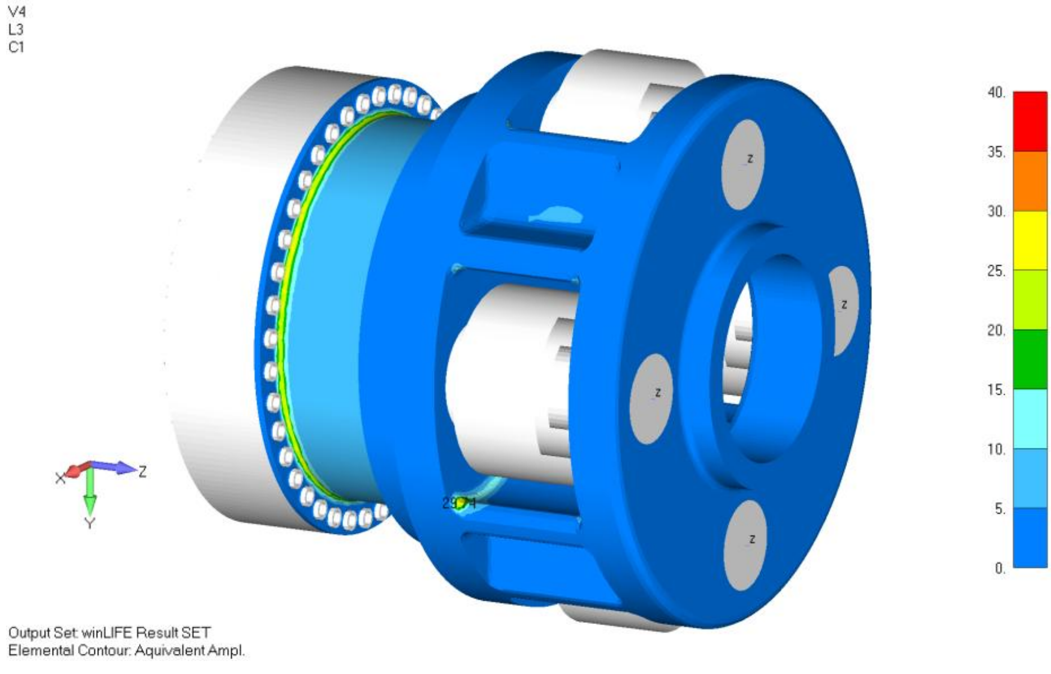


Figure 9: **equivalent amplitude for one scenario**

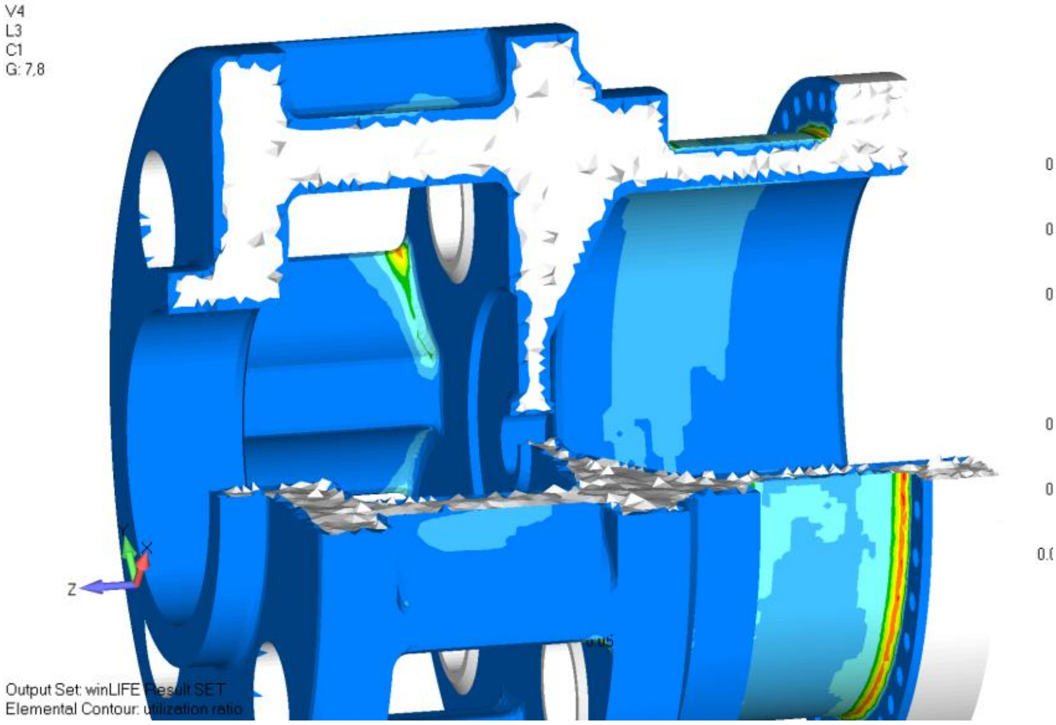


Figure 10: utilisation ratio for one scenario

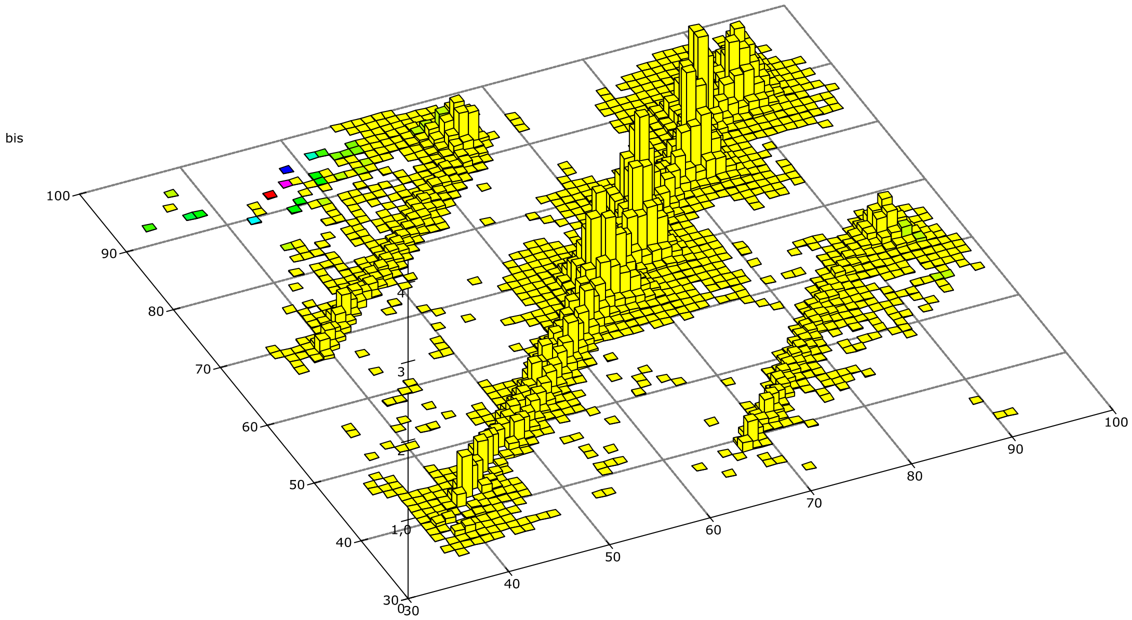


Figure 11: Rainflow-Matrix for the critical hot-spot

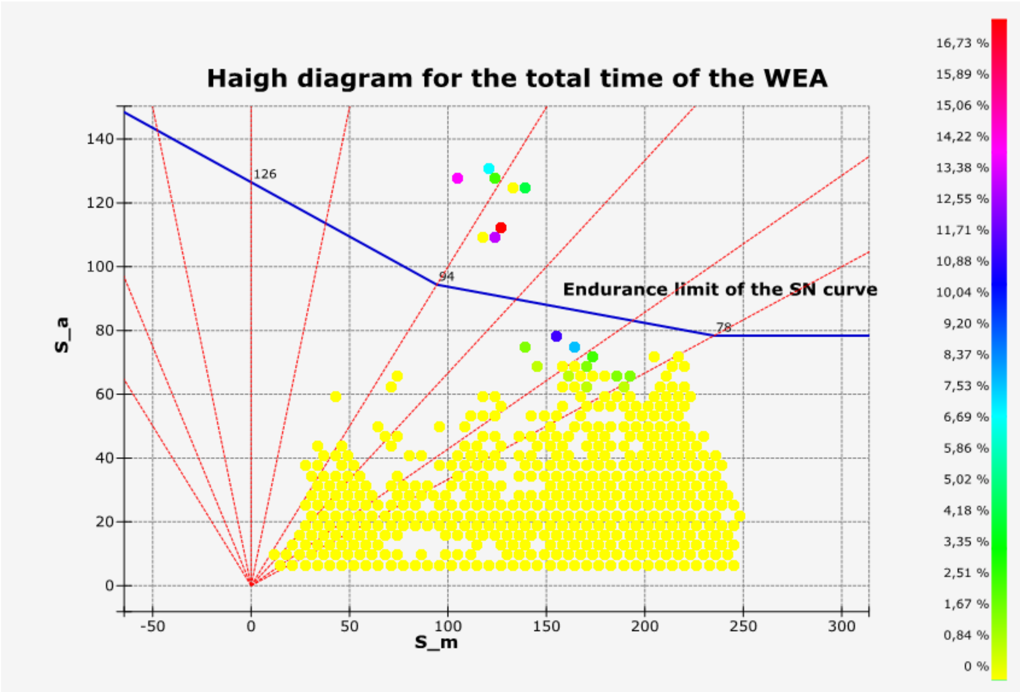


Figure 12: Haigh-diagram including the endurance limit (blue line) and stresses for each hysteresis

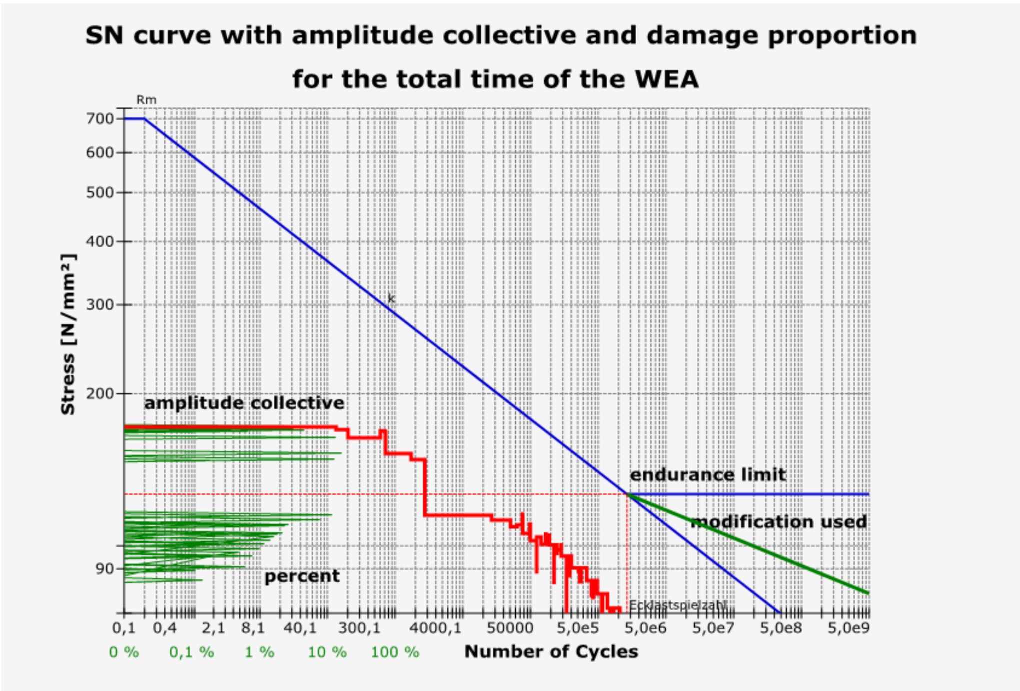


Figure 13: S N curve of the critical point (blue), Amplitude of the loading (red), share of the damage (green)

6.2 Final fatigue analysis using a finer mesh

The sub-model technique uses the results of the deformation of the global model which are border conditions for the sub-model. A finer mesh using sub-model with the following data was created:

Nodes of sub-model 1	193 908
Nodes of sub-model 2	319 969
Nodes on the surface (winLIFE Export) sub-model 1	4 610
Nodes on the surface (winLIFE Export) sub-model 1	10 517
Damage on hot spot 1	8.2E-11
Damage on hot spot 2	5.8E-12

The related stress gradient was used additionally for the local modification of the S-N curve.

The sub-model for the two hot-spots is shown in figures 14 and 15.

It can be seen, that not only the result has changed but also the order of the critical points.

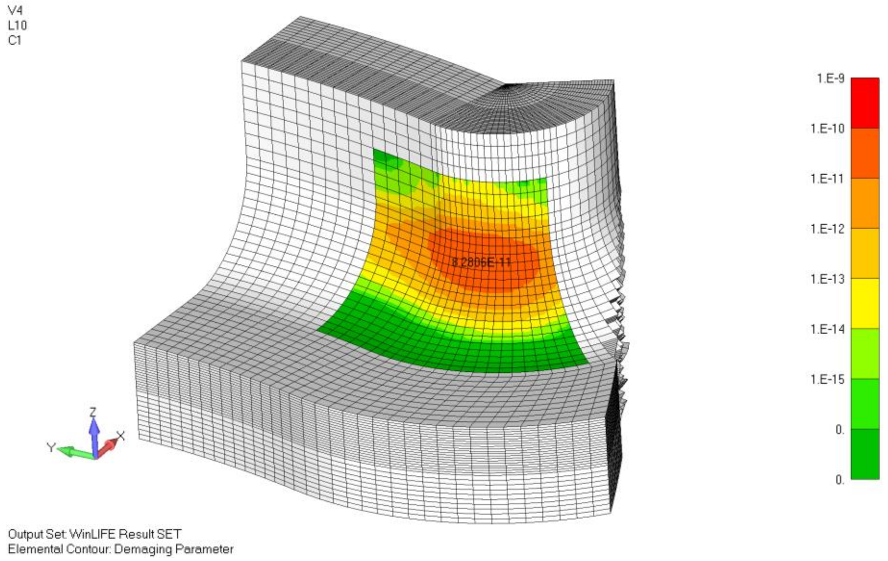


Figure 14: Sub-model including damage results for hot spot area 1

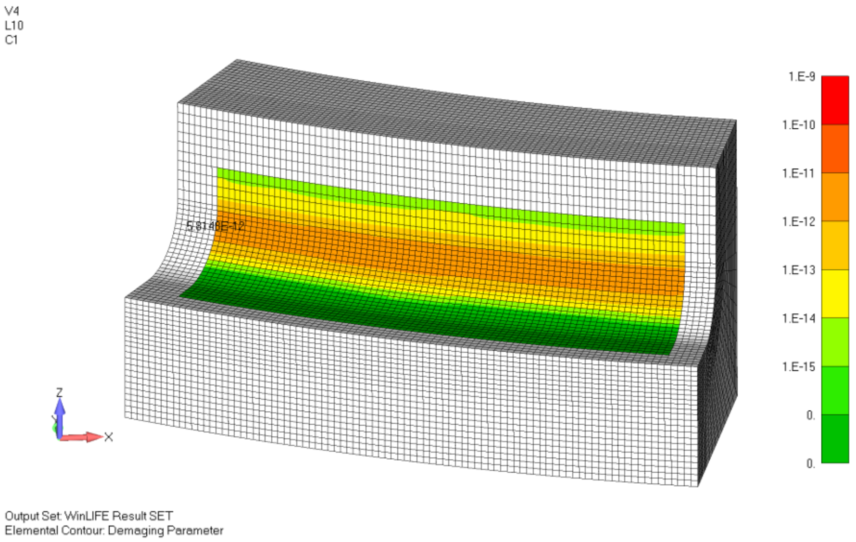


Figure 15: Sub-model including damage results for hot spot area 2

7. Summary and Outlook

Fatigue calculation in the way shown here is becoming more and more routine in the wind turbine industry using FEMAP with NX Nastran together with winLIFE.

Loadings coming from measurement or from simulation are used for the fatigue life prediction. It has been shown how the order of the scenarios can be taken into account by an additional mean load sequence.

The quality of the mesh is important for reliable fatigue predictions and the sub-model technique allows the user to do this in a simple way which gives a good mesh quality in combination with a limited model size.

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